

## 7. EXPERIMENT M-6, BONE DEMINERALIZATION

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### SUMMARY

Experiment M-6 was designed to determine the effect upon the skeletal system of prolonged weightlessness and immobilization associated with the cockpit of the Gemini V spacecraft. Accordingly, a bone demineralization study was conducted on both the primary and backup crews of the 8-day Gemini V mission utilizing the same method of radiographic bone densitometry as that of the Gemini IV flight. Radiographs were made pre-flight and postflight of the left foot in lateral projection and the left hand in posterior-anterior projection of each astronaut at (a) 10 days, 4 days, 2 days and on the morning of lift-off at Cape Kennedy; (b) on the aircraft carrier U.S.S. Lake Champlain immediately after recovery and again after 24 hours; and (c) at the Manned Spacecraft Center at 10 days and 58 days following recovery.

Since different X-ray units were used at the separate locales, the radiographs prepared for densitometry were standardized by three methods: (a) by the use of an aluminum alloy wedge exposed adjacent to the bone; (b) by use of a roentgen meter to determine the calibrated kilovoltage producing identical beam qualities in each of the three X-ray units; and (c) by exposing at each testing site a standard absorber composed of bone ash in an organic matrix (casein) and enclosed in a tissue-simulating absorber (plexiglass) to detect possible technique variations at the three locations involved.

Losses in X-ray absorbance between radiographs made immediately pre-flight and postflight (in terms of X-ray equivalent aluminum alloy mass) at the conventional os calcis tracing path were 15.1 percent in the command pilot and 8.2 percent in the pilot. When the immediate postflight value was compared with the average of the four preflight values the

losses were 19.3 percent for the command pilot and 9.0 percent for the pilot.

Losses in X-ray wedge mass equivalency in the distal radius - a bone not examined in Gemini IV - were -25.3 percent and -22.3 percent for the command pilot and pilot, respectively. In the talus of the left foot, also not examined in previous flights, a decrease of 13.2 percent occurred in the command pilot and a decrease of 9.8 percent in the pilot.

In interpreting these data, it should be understood that changes in X-ray absorbency of bone involve not only calcium, but also other mineral constituents of calcium hydroxyapatite (the chief mineral component of bone), as well as interstitial and over- and underlying protein.

## METHODS

### Bone Densitometer Assembly

The instrumentation used in the photometric evaluation of bone density is a special analog computer consisting of a series of subassemblies, all designed to operate together as a completely integrated system. The theoretical aspects and instrumentation have been described in detail in references 1 and 4. The history of the development of the method and some specific applications of the method have been reported in references 2, 3 and 7.

### Standard Radiographic Exposure Technique

The three diagnostic X-ray units used in the study were standardized with a central unit at Texas Woman's University by means of a calibration curve relating kilovoltage with the X-ray transmittance in milliroentgens through a standard 2-millimeter aluminum filter under a specific X-ray intensity. Under the exposure conditions utilized, all units yielded a beam quality equivalent to 60 kilovolts to assure a constant relationship among the mass absorption coefficients of hydroxyapatite, water, protein, fat, and aluminum alloy.

### Evaluations of Wedge Mass Equivalency

In the previous investigation of bone mass changes before, during, and after the Gemini IV flight, two bones were examined: (a) the left os calcis or heel bone, and (b) phalanx 5-2 of the left hand. In the current study the same two bones were examined with the addition of

phalanx 4-2, the distal end of the left radius, and the left talus. The anatomical sites examined are discussed in the following part, and are illustrated in figures 7-1 through 7-4.

Central os calcis section.- This anatomical site was used in the M-6 experiment in the Gemini IV flight and has been repeated in the Gemini V mission. The tracing path across the left os calcis in lateral projection (fig. 7-1) runs diagonally between conspicuous posterior and anterior landmarks which, by superimposing successive radiographs, can be accurately reproduced in serial films of the same individual. This single path (1.3 mm in width) is known as the "conventional scan."

Multiple parallel os calcis evaluations.- Approximately 60 percent of the total os calcis mass is evaluated in the parallel path system. After making the conventional scan, a series of parallel paths 1.0 millimeter apart were scanned beginning 1 millimeter above the conventional path and continuing to the lowest portion of the bone. The total number of paths scanned is therefore proportional to the size of the bone which, of course, has individual variations. For the command pilot 34 paths were required to cover the os calcis portion examined, while 35 parallel scans were needed for the pilot. Figure 7-2 illustrates the alinement of parallel paths through the os calcis portion examined although not every path is shown in the illustration.

Sections of the phalanx 4-2 and 5-2.- The second phalanx of the fourth and the fifth finger of the left hand was scanned by parallel cross-sectional paths 1 millimeter apart alined tangentially with the longitudinal axis and covering the entire bone area (fig. 7-3).

Distal end of radius.- A single scanning path was made through the diaphysis of the left radius parallel to the distal surface (fig. 7-4).

The talus.- A single scanning path was made through the talus of the left foot originating at the inferior surface and projecting anteriorly to the conspicuous landmark shown in figure 7-1.

#### INTERPRETATION OF THE TERM, "X-RAY ABSORBENCE" BY BONE

The term "X-ray absorbence" by bone as used in this report refers to the beam attenuation resulting from the hydroxyapatite and water-organic contents in their relative weight concentrations together with the over- and underlying soft tissue. Although changes in composition or thickness of the overlying soft tissue could account for slight changes in total X-ray absorption, our tests have shown that in the case of the os calcis, errors accountable to changes in soft tissue mass are

slight, with changes in thickness of one millimeter accounting for X-ray absorption changes of approximately one percent.

## RESULTS

### X-ray Absorption Changes in the Central Os Calcis Section

#### (Conventional Path)

The X-ray absorption values (in terms of calibration wedge equivalency in grams) obtained from the central os calcis section during the Gemini V study are shown in figure 7-5 and table 7-I. Based on an average of all four preflight wedge equivalency values, the command pilot showed a change of 19.3 percent in this section of bone, with a 15.1 percent change when the immediate postflight film was compared with that made immediately before launch. The corresponding values for the pilot were 9.0 and 8.2 percent. Recovery was substantially complete in both astronauts on the 28th day (10 days postflight), and full recovery had occurred by the 75th day (58 days postflight).

### Changes in Multiple Sections of the Os Calcis

Thirty-four parallel scans were made of each os calcis radiograph of the command pilot and 35 scans were made of the radiograph of the pilot covering approximately 60 percent of the total bone mass in each astronaut (fig. 7-2).

Figure 7-6 indicates that the values immediately following the flight and 24 hours after were lower than any of the preflight values with a 10.3 percent decrease in the command pilot and an 8.6 percent decrease in the pilot. Complete recovery had occurred by the 75th day (58 days postflight).

### Comparison of Four Groups of Os Calcis

#### (Parallel Sections)

In an effort to determine which regions of the os calcis are the most sensitive reflectors of changes on bone mass, the multiple scans were divided into four groups each represented by a longitudinal section of bone approximately 9-10 millimeters wide. The changes between the



preflight and postflight values of four sections for each astronaut were the following:

- (1) Superior section (segments 1 millimeter above the scan through segment 8 below)

Command pilot . . . . .	-12.8 percent
Pilot . . . . .	- 8.5 percent

- (2) Second section (segments 9 through 18 below the conventional scan)

Command pilot . . . . .	-11.8 percent
Pilot . . . . .	- 9.1 percent

- (3) Third section (segments 9 through 18 below the conventional scan)

Command pilot . . . . .	- 4.4 percent
Pilot . . . . .	- 7.5 percent

- (4) Inferior section (segments 28 to inferior surface of os calcis)

Command pilot . . . . .	- 4.7 percent
Pilot . . . . .	- 7.5 percent

As expected, there is some inconsistency in the magnitude of changes from section to section. However, it is apparent that the bone mass decreased somewhat more in the superior sections than in the inferior sections in both astronauts. This effect may be attributed to the greater proportion of cancellous to cortical bone in the superior regions than in the inferior regions of the os calcis, explaining the fact that changes of greater magnitude are often seen in the conventional scanning path than in multiple scans of the entire bone.

#### Changes in the Distal Area of the Radius

During the 8-day Gemini V flight, the X-ray wedge mass equivalency of the distal end of the left radius decreased by -25.3 percent in the command pilot and by -22.3 percent in the pilot. The preflight values were regained in both astronauts by the 75th day (fig. 7-7).

### Changes in the Talus

The X-ray wedge mass equivalencies at the talus scanning site made immediately postflight was 13.2 percent lower than the final preflight value in the command pilot, and 9.8 percent lower in the pilot. Recovery was faster in the talus than in the radius, however, with both astronauts exhibiting almost full recovery on the 27th day (18 days postflight) and full recovery by the 75th day (58 days postflight).

### Bone Mass Changes in Hand Phalanges 4-2 and 5-2

As in the case of the os calcis, multiple parallel scans were made across hand phalanges 4-2 and 5-2 so that the entire area of each phalanx in posterior-anterior projection was evaluated (fig. 7-3). Decreases in wedge mass equivalency were noted in both phalanges during the 8-day orbital phase of the study, although in both astronauts the decrease in phalanx 5-2 was greater than that in 4-2. In the command pilot a 22.6 percent decrease in wedge mass equivalency occurred when the immediate postflight value was compared with the average of the four preflight films, and the pilot decreased by 24.5 percent. In hand phalanx 4-2, decreases of -6.2 and -6.4 percent occurred in the command pilot and pilot, respectively (figs. 7-9 and 7-10).

### RELATION OF SPACE FLIGHT FINDINGS TO FINDINGS FROM TWU BED-REST STUDIES

In this Gemini V study, an amount of 845 milligrams of calcium was provided per day for each man during the orbital flight. On the other hand, a mean of only 373 milligrams daily was consumed by the command pilot, and a mean of 333 milligrams by the pilot.

In the TWU bed rest, one group of men was placed on an extremely low level of calcium, with mean daily levels consumed tending to be even slightly below those of the Gemini V astronauts. Table 7-II summarizes the comparative wedge mass equivalency changes in the central os calcis section for both astronauts and for four bed-rest subjects on similar average levels of calcium for similar periods of time.

## DISCUSSION

Densitometric evaluations of serial radiographs of "normal" subjects have often shown rather frequent changes in bone mass within relatively short periods of time. For this reason it was decided to make two pre-flight and two postflight radiographs of the Gemini V backup crew. In comparing the changes observed preflight and postflight as the conventional os calcis scanning site between the two crews, it was found that no changes greater than 4 percent were evident in either member of the backup crew. This is in contrast to the 15.1 and 8.9 percent losses observed in the prime crew.

It has long been known that the skeletal system experiences a general loss of mineral under immobilization or extended bed rest. However, in both Gemini IV and Gemini V studies, bone mass losses were greater in both the os calcis and phalanx than were shown by the TWU bed-rest subjects during the same period of time.

Although the bone mass losses in the 8-day Gemini V flight were generally greater than in the 4-day Gemini IV flight, the information to date is still insufficient to conclude that the losses tend to progress linearly with time, or whether a form of physiological adaptation may occur in longer space flights.

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TABLE 7-I.- EVALUATION OF CENTRAL OS CALCIS POSTERIOR-ANTERIOR

## "CONVENTIONAL" SEGMENT

## (a) Command pilot

Radiographs	X-ray absorption values in terms of aluminum wedge equivalency, grams
Mean of values from preflight films	2.0205
Film taken immediately before lift-off	1.9193
Film taken immediately after end of flight	1.6295
Film taken 10 days after end of flight	1.9215
Film taken 58 days after end of flight	2.0101

## (b) Pilot

Mean of values from preflight films	1.8214
Film taken immediately before lift-off	1.8169
Film taken immediately after end of flight	1.6574
Film taken 10 days after end of flight	1.7762
Film taken 58 days after end of flight	1.8160

TABLE 7-II.- COMPARISON OF WEDGE MASS EQUIVALENCY LOSSES IN CENTRAL  
OS CALCIS OF GEMINI V CREW AND OF TWU BED-REST SUBJECTS  
ON SIMILAR DAILY INTAKES OF DIETARY CALCIUM FOR SIMILAR PERIODS OF TIME

Subjects	Number of days	Average calcium consumed/day, milligrams	Central os calcis wedge mass equivalency change, percent	
			Based on mean of preflight values	Based on last value before launch
Command pilot	8	373	-19.3	-15.1
Pilot	8	333	-9.0	-8.2
TWU Bed rest	8		X	Based on value before bed rest
Subject 1				-8.65
Subject 2				-5.06
Subject 3				-7.89
Subject 4				-8.06

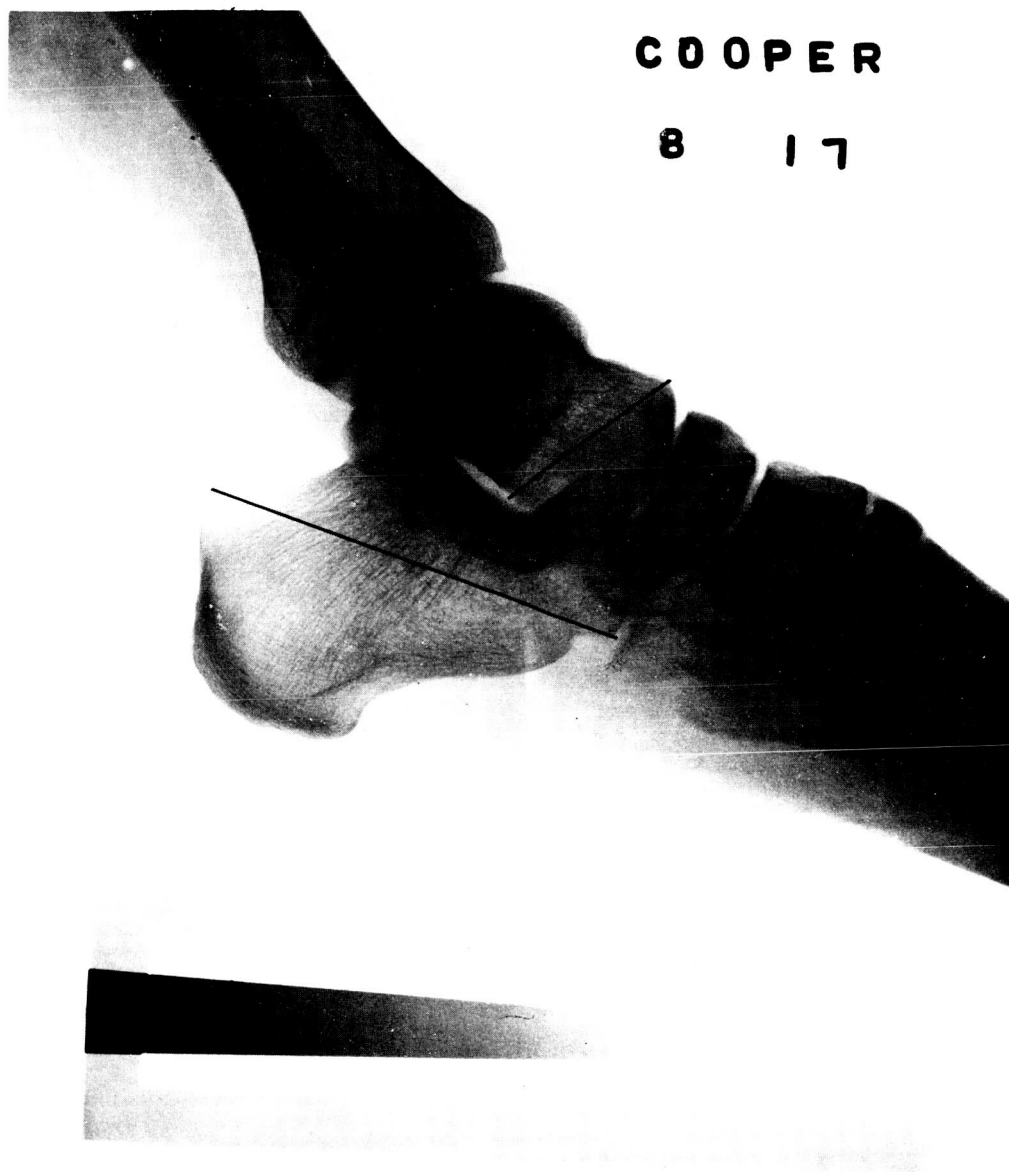


Figure 7-1.- Reproduction of positive of the lateral radiograph of the left foot of the Gemini V command pilot indication conventional scanning paths of os calcis and talus.

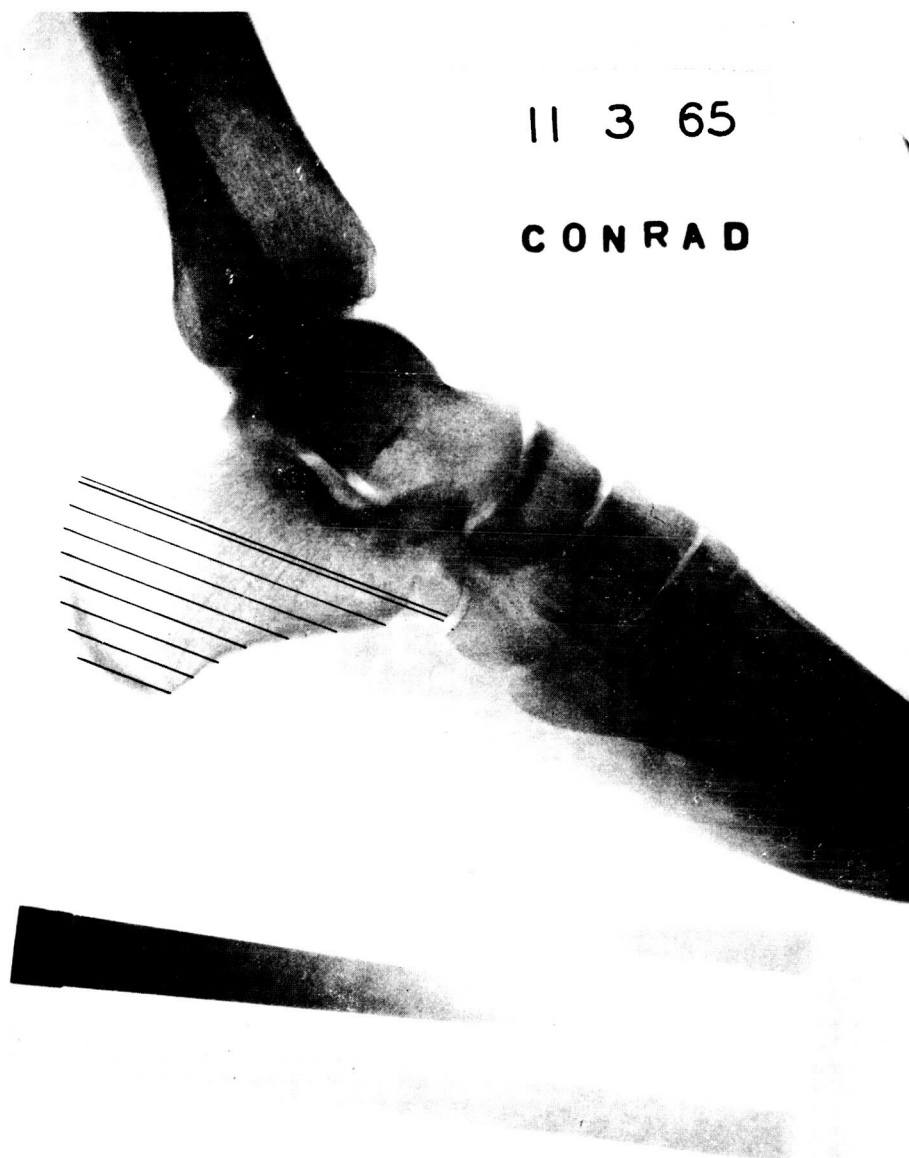


Figure 7-2.- Reproduction of the positive of the radiograph of the left foot of the Gemini V pilot indicating multiple parallel paths.





Figure 7-3.- Reproduction of the positive of the radiograph of the left hand of the Gemini V pilot indicating parallel paths of phalanges 4-2 and 5-2.

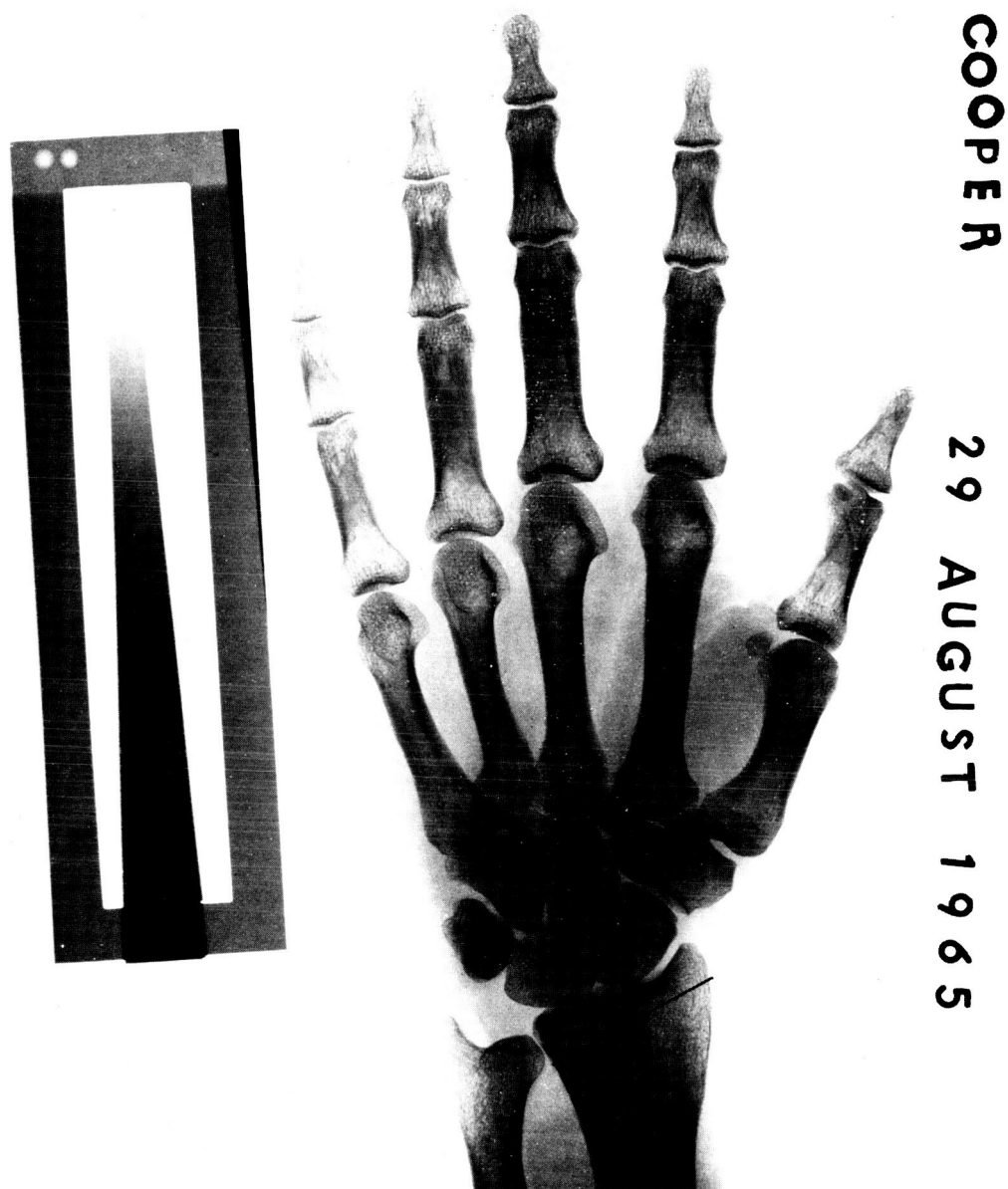


Figure 7-4.- Reproduction of the positive of the radiograph of the left hand of the Gemini V command pilot indicating the scanning path of the distal radius.

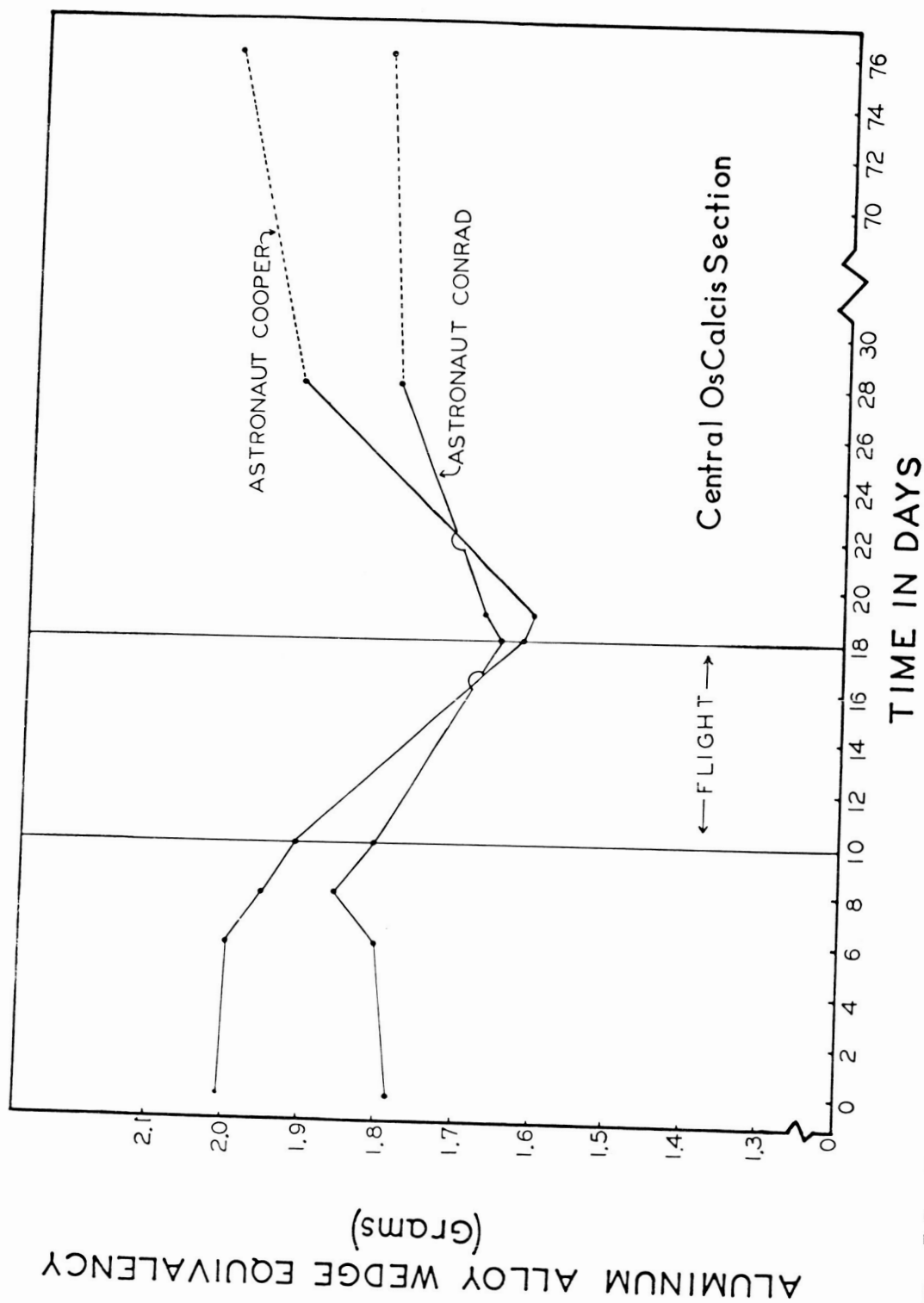


Figure 7-5.- Changes in aluminum alloy wedge mass equivalency of the central os calcis segment ("conventional path") of the Gemini V command pilot and pilot throughout the Gemini V program.

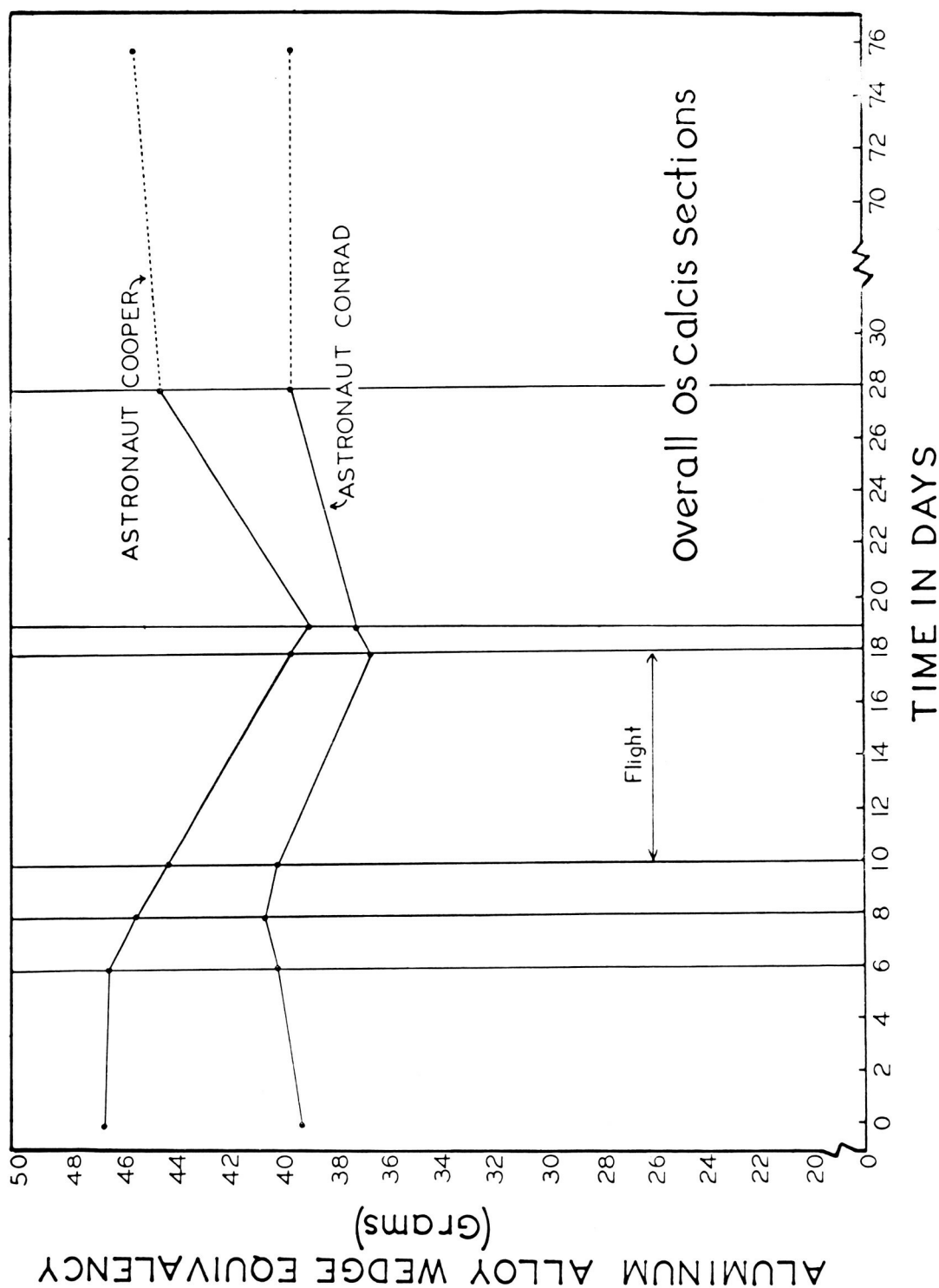


Figure 7-6.- Changes in aluminum alloy wedge mass equivalency of the entire series of parallel scans of the os calcis of the Gemini V command pilot and pilot.

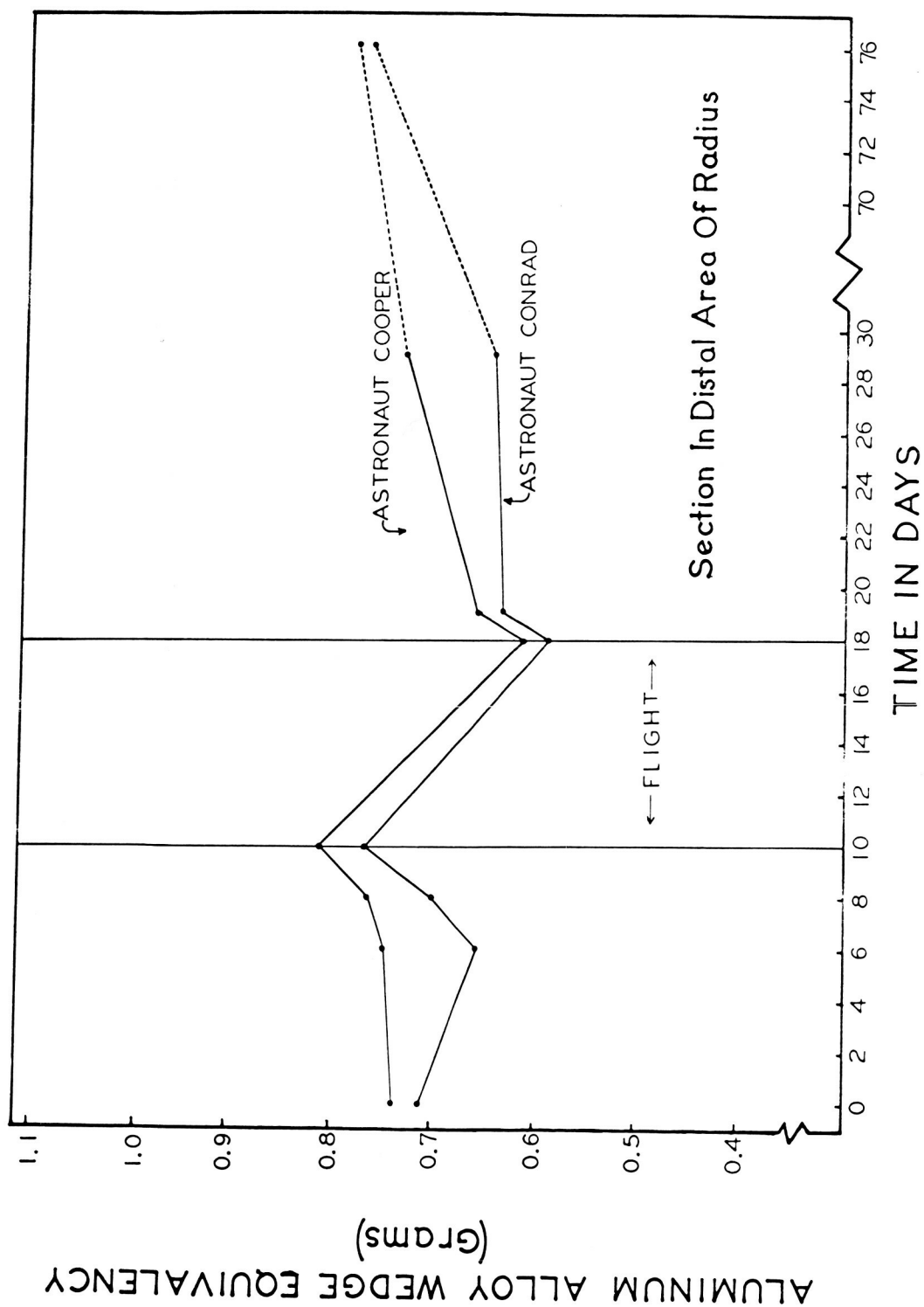


Figure 7-7.- Changes in aluminum alloy wedge mass equivalency of the distal end of the radius of the Gemini V command pilot and astronaut.

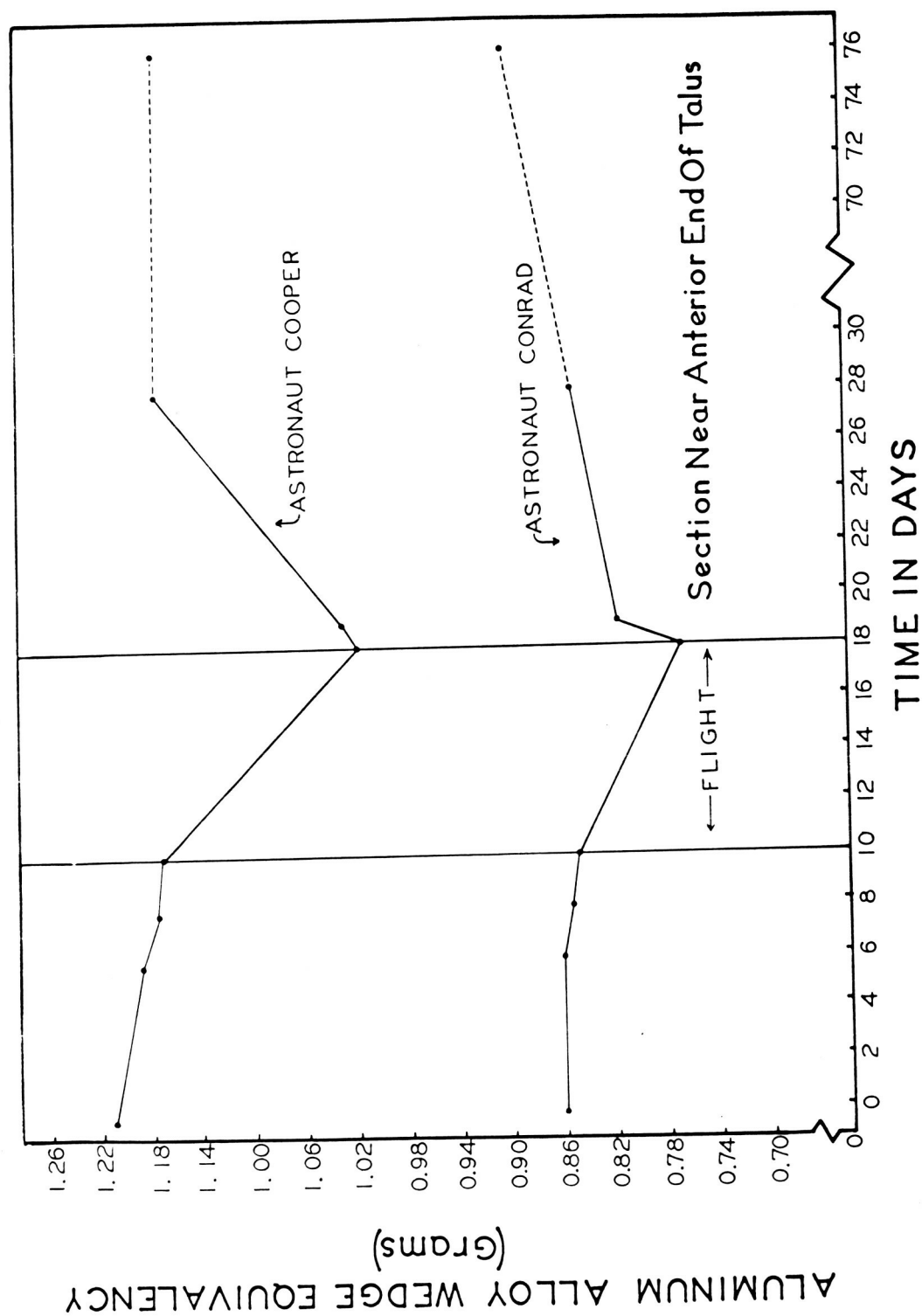


Figure 7-8.- Changes in aluminum alloy wedge mass equivalency of the talus of the Gemini V command pilot and astronaut.

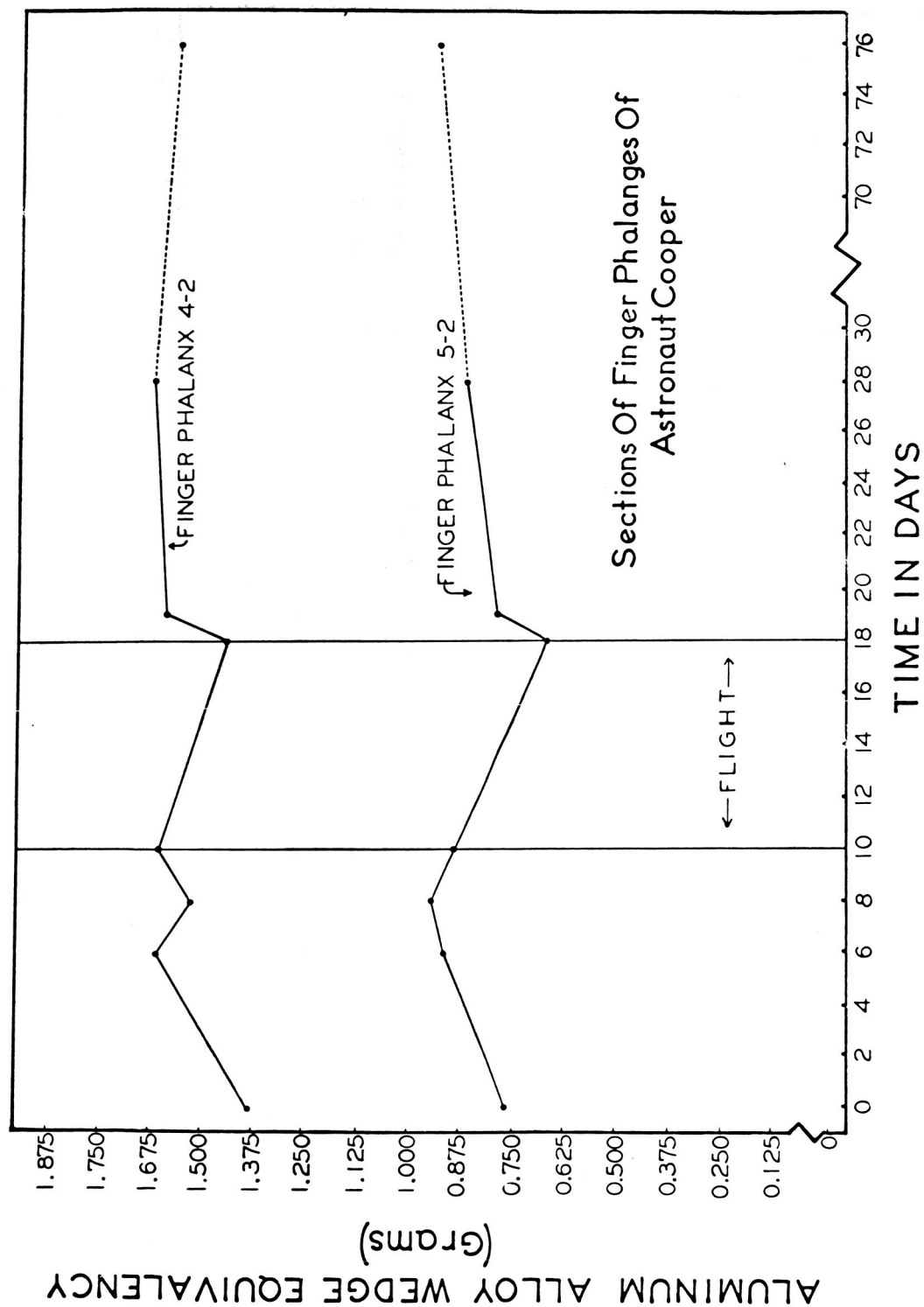


Figure 7-9.- Changes in aluminum alloy wedge mass equivalency of hand phalanges 4-2 and 5-2 of the Gemini V command pilot.

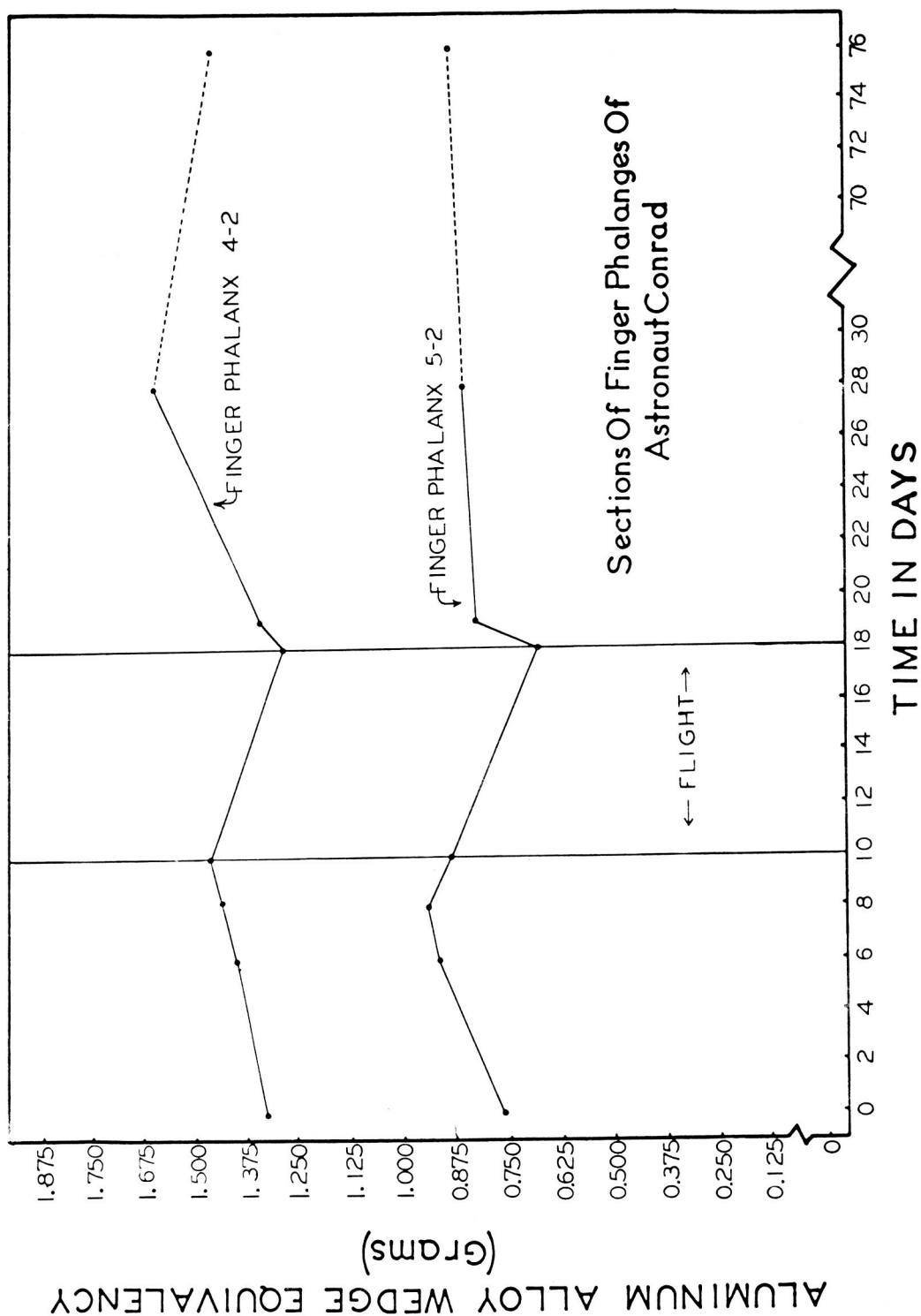


Figure 7-10.- Changes in aluminum alloy wedge mass equivalency of hand phalanges 4-2 and 5-2 of the Gemini V pilot.